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Event: Astronomical Telescopes and Instrumentation, 2002, Waikoloa, Hawai'i, United States

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Keck Interferometer: From development phase to Facility Class Instrument

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ABSTRACT

The Keck Interferometer is entering a regular limited observational phase. A restricted number of observers are expected to use the instrument over the course of the next few years in a shared-risk capacity. To facilitate this, the W. M. Keck Observatory and the Jet Propulsion Laboratory are following a Handover procedure consisting of a number of stages related to the science modes of the instrument as they reach completion. The first of these is the Visibility Science mode that involves only the two Keck telescopes. Other modes to follow are Nulling, Differential Phase, Astrometry, and Imaging. The process includes defining a reasonable level of functionality of each mode, training observatory staff to maintain and schedule tasks related to the upkeep of each mode, and defining and documenting each of the subsystems related to each mode. Here we discuss the outline of the Handover plan and report on its progress to date.

Keywords: Interferometry, Keck Interferometer

1. BACKGROUND

The Keck Interferometer is entering a phase of observational operations. A limited scientific program has been executed during the most recent runs from observers from NASA shared-risk science teams and the California Institute of Technology. Most interferometers to date have not typically been available – outside of the team/institution responsible for the interferometer's conception, development and construction. The transition of the Keck Interferometer from development phase to facility class is also unique in a further number of ways. It is the one of the initial, and few, instances that an interferometer has been built around an existing observatory. As such, it contends with scheduling of an operational facility as well as the observatory's operating environment. Vibrations from the observatory's plant and machinery, in particular, are a major issue and are addressed elsewhere in these proceedings[1]. However, the current interferometer functionality is the first of its scientific modes, so the transition to facility class must not only ensure the functionality of the science modes as they become available, but also not impede the development of the instrument and be responsive to uncharacterized and unexpected hurdles of retrofitting an interferometer into an existing observatory.

The process of handing over a one-of-a-kind astronomical instrument from the development team to an observatory operations group is frequently challenging. In the case of the Keck Interferometer, this process is made more difficult by the scale, complexity, and exotic nature of the instrument. However, if the instrument is to be a long-term scientific success, it is imperative that this Handover process be executed, and executed well. We describe the process developed for Handover of the Keck Interferometer with the hope that at least portions of this discussion will be useful in the context of other complex instrument systems.

The instrument involves numerous active control systems and back-end focal plane instruments, as well as a variety of observing modes. In complexity and scope, the Keck Interferometer is more akin to an observatory than an instrument; any Handover plan for the instrument must function in this context. Resulting from the scale of the instrument and the need for the development team to continue development, the W. M. Keck Observatory (or the California Association for Research in Astronomy (CARA)) and the Jet Propulsion Laboratory (JPL), are using a "phased" Handover approach

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rather than handing over the entire instrument at the end of the project. In this phased Handover paradigm, the Visibility Science mode is handed over to the observatory first. We have intentionally separated the functional (observing mode) handovers from subsystem handovers. This is because many of the subsystems are not in their final form, but they do function adequately for visibility mode observing. The subsystems will continue to be upgraded both to enhance the Visibility Squared science observing mode and to enable other observing modes that follow.

The phased Handover approach has several benefits. First, it makes the Handover of the instrument more of a partnership because the observatory gains functional domain knowledge regarding the instrument at a relatively early stage; compared to Handover at end. The relatively early Handover of a science observing mode also increases observatory ownership and stake earlier in the instrument development process. Second, a phased Handover allows for changing details of the Handover process for future observing modes in light of "lessons learned" with the first mode; it will also serve as a means to gauge the success of this approach for the other science modes that follow. And thirdly, the phased Handover allows the development team to concentrate more on development.

1.1. The Keck Interferometer

The Keck Interferometer, when complete, is envisaged to have five different observing modes, these are: Visibility Squared, Nulling, Differential Phase, Astrometry, and Imaging. The Handover described here is that of the Visibility Science mode using the two Keck telescopes.

Currently, the Keck Interferometer[2] is a single baseline instrument utilizing the two 10-m Keck telescopes on an 85-m long baseline. Interferometric phasing is achieved through two sets of delay lines. The first is the Long Delay Line (LDL) that is static during an actual observation that removes the bulk of the path difference. The other is a dynamic system, the Fast Delay Line (FDL), that tracks delays (up to 20 m) during observations. Beam propagation through both delay lines is with a 4" beam before it is compressed to a 1" diameter close to the fringe tracker in the basement of the facility. This tracker (FATCAT) is a fiber-fed focal plane detector using a Rockwell HAWAII chip. To maximize use of the full 10-m input diameter, each Keck telescope has an Adaptive Optics system[3] at the Nasmyth level. Star tracking and primary beamline stabilization is performed by an angle-tracker (KAT), also a focal plane HAWAII detector, in the basement that operates in conjunction with each Adaptive Optics system and a pair of tip-tilt mirrors. Further beamtrain OPD stabilization is achieved with: feedback to the FDL from laser metrology of the entire beam path and feedforward to the FDL of telescope piston measured with accelerometers; additional beamtrain tilt stabilization is achieved using a closed-loop angle servo sensing the tilt of an internal stimulus. Figure 1 shows the basic layout of the major subsystems of the interferometer.

A pair of siderostats, each 0.5-m diameter, originally installed to facilitate the testing of interferometer hardware and software, are available for guiding starlight into the interferometer. These are located alongside the observatory with a baseline of 20 m aligned approximately parallel to the Keck-Keck baseline. The interferometer can be switched between Keck-Keck and siderostat operation by repositioning a pair of mirrors. The siderostats still have a role with hardware and software testing, and also serve as a central tool for training Keck staff as part of the Handover process.

1.2. Handover Definition

The initial Visibility Science Handover identifies the ensemble of tasks which, when completed, will allow CARA personnel to achieve science-grade visibility measurements with the interferometer. This is an *intermediate* Handover – meaning that its purpose is to outline a minimal set of functionality necessary for carrying out the science program. Consequently, completion of this observing-mode Handover is separate from that of a hardware or software subsystem handover.

The intent of the Visibility Science mode Handover is to have the Keck Observatory take on the routine operational work associated with running the Keck Interferometer. This includes internal and beam train alignments, pre-run validation of subsystem function, and operation of the instrument for visibility science and engineering observing. What is being handed over, assuming all systems are functional, is the responsibility for delivering and operating the Keck Interferometer on the sky with an expectation of acceptable data quality.

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It is a given that the instrument functionality and performance will increase after the Handover. This could mean, amongst other things, fewer staff would be needed for setup or visibility data could be obtained from fainter objects. But changes to the instrument are considered functional upgrades and do not change the intent of the visibility Handover.

As our Handover process progresses, we find the following questions and concepts useful to consider; these points also helped our project arrive at the process for how we execute the Handover.

- What is being handed over?
- What does a handover mean?
- The distinction between documentation and institutional knowledge
- The institutionalization of knowledge
- Clear identification of personal roles for operations
- Sky time must be devoted to validate the process

1.3. Organization

Below we outline various activities, documents, and practices associated with conducting visibility science. These items are further subdivided to create a hierarchical view of the work required. Where appropriate, staff members from both CARA and JPL will be assigned the job of validating all the individual items associated with a particular category. A review will be held to verify that the requirements for the Handover categories discussed below have been satisfied completely.

To further facilitate the institutionalization of knowledge of interferometer operations amongst CARA staff, the use of siderostats is essential. As mentioned above, siderostat operation provides a means of training staff outside Keck-Keck observing runs, so that such activities can be performed without using, or risking, expensive telescope time. Most of the routines for the Visibility Science mode, defined below, can be tried, tested and refined in this way. Once honed, these tasks can be passed on to appropriately identified personnel.

In this paper we present the definition of the Visibility Science mode Handover plan and outline its scope, tasks, and character. We conclude by briefly reporting on its progress to date.

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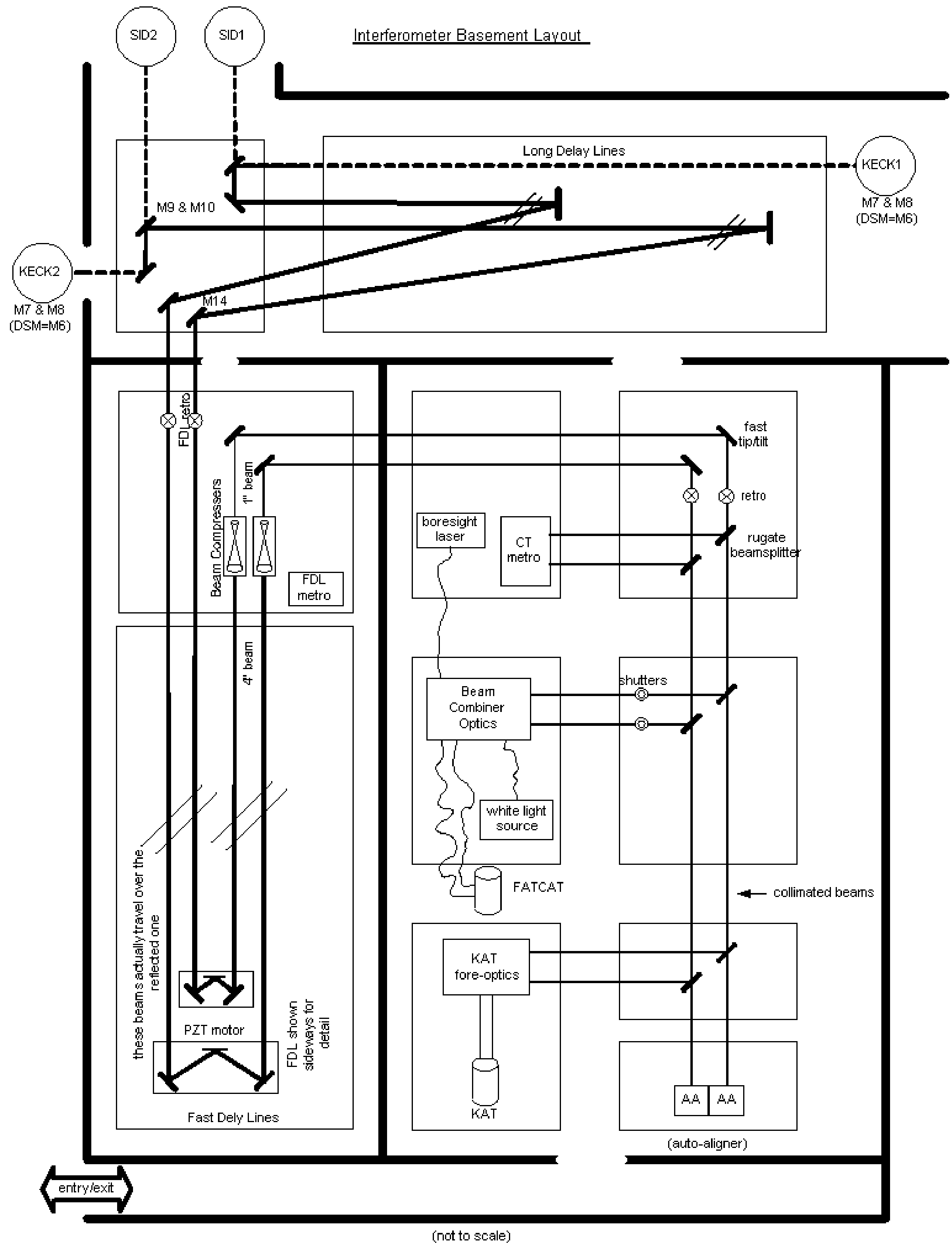

Figure 1: Schematic of the layout of interferometer hardware in the basement of the Keck Observatory on the summit of Mauna Kea. (Courtesy of Kevin Tsubota, W. M. Keck Observatory.)

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2. THE HANDOVER PLAN

The motivating goal of the Visibility Squared mode Handover is have an interferometer that is capable of routinely achieving well-calibrated fringe visibilities commensurate with the science program when operated by CARA personnel. To achieve this goal, the Handover task was broken down into three separate categories: Routine, Fringes and Operations; with further detail shown in Fig. 2 and described below.

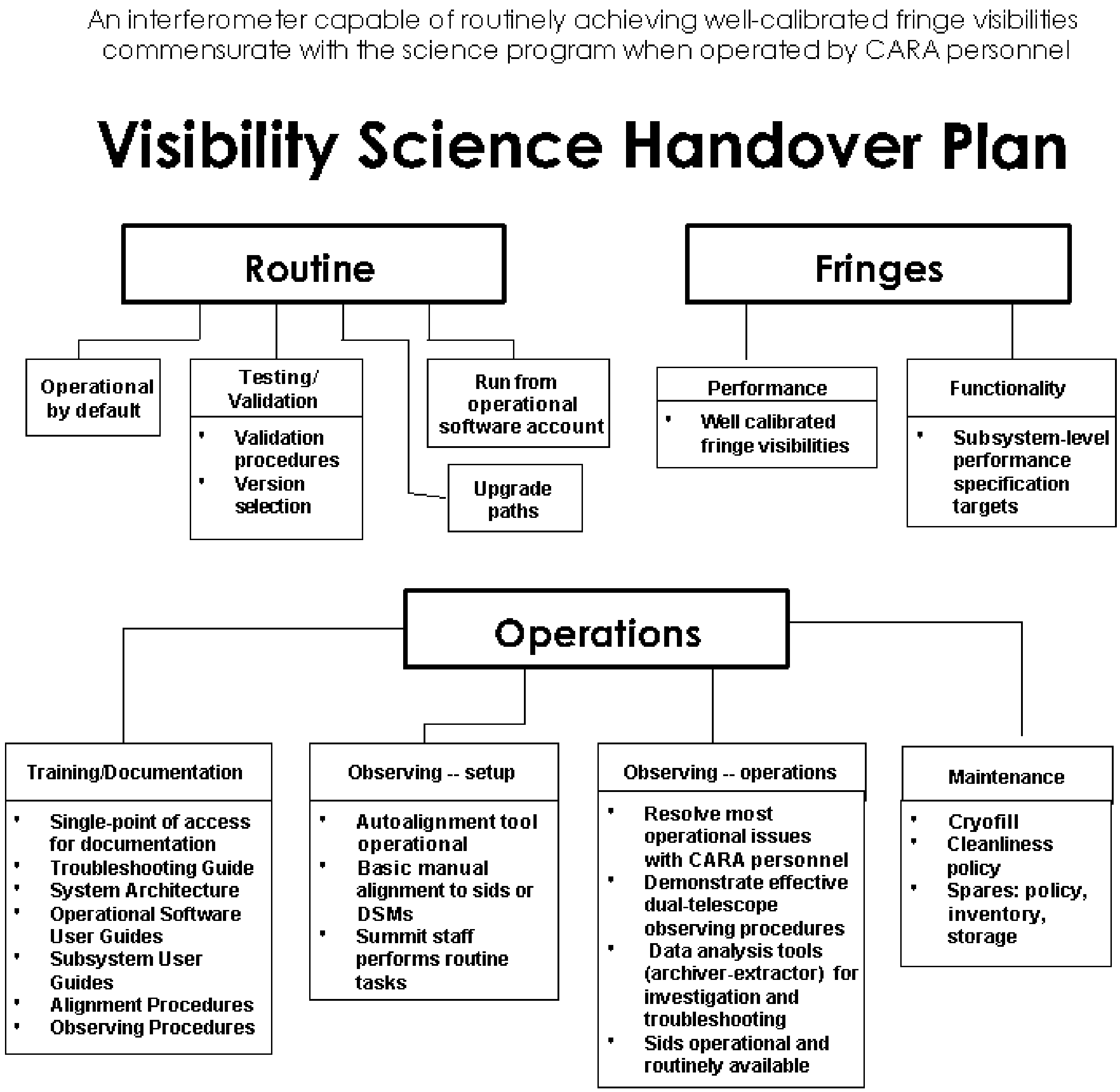

Figure 2: Visibility Science Handover plan viewed as a top-down view hierarchy from the overall goal of the Handover.

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2.1. Routine

While the interferometer will operate as a facility class instrument in the Visibility Science mode, it still finds itself under development and the environment it runs is still one of a developmental nature. To facilitate all the uses of the instrument for development, installation of new hardware/software, training, and operation as the Handover proceeds, a number of guidelines have been/are being implemented:

- **Operational by default.** The interferometer should be available, out to the Dual Star Modules (DSMs or Nasmyth deck) or siderostats, by default, unless arrangements are made in advance. The development team will have priority in access to the system. They can reserve any and all subsystems for exclusive use for whatever period is deemed necessary. Access will be coordinated by use of a schedule showing half day blocks of time and the owner of that block. *Operational by default* simply means that all blocks will be available to all, until they are assigned otherwise. This is intended to make visible the subjective goals of reliability and to make it easier to coordinate the activities of diverse groups.
- **Testing and Validation.** As instrumental development proceeds, there should be developed a means of validating old functionality against the added features in hardware and software. We imagine that a set of standard tests (using the white light source on the interferometer or the AO system) and on-sky observations may serve this purpose in many cases, possibly using the siderostats. These tests and procedures must be demonstrated as part of the Handover process.
- **Fully-functional operational software account.** It is essential that we provide routine operational control of the interferometer though an account other than that used for development. That account will use software versions and system configurations known to work. A well-defined process for upgrading this account will be provided and followed.
- **Upgrade Paths.** Since it is known at the inauguration of this plan that not all the features required for long-term visibility science mode operations will be in place before this intermediate Handover, it is advantageous to anticipate changes, and to document these as they occur.
- **Spares Policy.** Determination of an appropriate spares policy, coordinating with other observatory instruments as appropriate. Certain off-the-shelf components may be common to several systems at Keck.

2.2. Fringes

A performance goal of achieving visibility calibration on faint sources suitable for shared risk science teams is the main driver for most of the Handover process. However, at this early stage of development, the emphasis is on having a well-characterized mode, rather than, say, the ultimate in sensitivity. Having specified the goal this way, we concentrate on procedures and requirements to achieve this goal. Should the performance of particular subsystems, or procedures, be identified as limiting the minimal requirements of the overarching science goal, specific tasks related to that subsystem might be added to this plan.

The hardware and software performance specifications for all interferometer components are largely those of the JPL/CARA development team. As this Handover is focused on an operations nature, rather than a subsystems one (yet to occur), no further mention of hardware and software performance specifications will be made here.

2.3. Operations

Here lies the true heart of the operational Handover process – the passing on of knowledge of running a complex instrument. We describe the end products of this process as well as the means of achieving this goal as well as listing some of the identified requirements for sustained interferometric observing.

2.3.1. Training and Documentation

Training and documentation lie at the heart of this Handover plan, since it covers only a science mode and does not include any particular subsystems. In particular:

- **Startup and Shutdown.** A complete set of instruction for bringing the system (hardware and software) up from a completely cold, shut-down state.

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- **System Safety.** This is a document describing system components that are sensitive to damage. For example, detectors sensitive to static discharge, or any order dependence in the way systems are powered up.
- **Drawings and Diagrams.** Various views of the interferometer are helpful tools. One example of a drawing of this type is the alignment schematic shown in Fig. 3. Another example is the overall layout drawing of Figure 1. Both are the result of the process of generating documentation described below.
- **Alignment Procedures.** These have broken down the alignments into separate procedures, as shown in Fig. 3, to make it easier to organize and structure the information. The arrows give some idea of the interdependencies of the various sub-alignments. A procedure will be written for each of these sub-alignments**.** Observatory staff should be able to carry out each of these alignments, individually, and demonstrate end-to-end alignment adequate for science programs.
- **Single point of access to documentation**. All the operational documentation will be maintained in such a way that it can be located and referenced from one source.

The details of the procedure by which the above is produced is now described. The operational details of the Handover plan are generated by enabling the following sequence. The operations staff has the lead role in generating the plan with input from the development team. The training and documentation aspects of the Handover occur quasi-concurrently; incorporating the draft documentation supplied by the development team into the training process of the operations team provides valuable feedback for documentation revisions. The sequence is as follows:

1. Identify tasks
2. Draft documentation for procedures in each role
3. Train two people in each role (no single point of failure)
4. Require that they train a third (CARA) subject to development team review
5. Identify roles (responsibility for collection of tasks)
6. Validate process and documentation with
    a. CARA participates in process/task
    b. CARA executes procedure/task with development team support
    c. CARA executes procedure/task independently
    d. Final test is CARA-only operation on sky
7. Development team delivers documentation for experts
8. Operations team delivers documentation for technicians

Identifying the tasks necessary to execute the Visibility Science Handover was done by breaking the interferometer down into functional units (fringe tracking, angle tracking, adaptive optics, etc.). The subsystem leads then put together an initial set of instructions for other development team members. Those instructions were then used by other development team members to operate the subsystem and the instructions were updated based on that experience.

Draft documentation is prepared for each task or process. This documentation, together with a member from the development team, provides the basis for training operations staff. To avoid single points of failure, we require that at least two operations staff be trained for each task by a development team member.

Resulting from the differences between a development and an operations environment, we have chosen to divide the documentation responsibilities between the development and operations teams. The development team is responsible for writing documentation that can be used by interferometer scientists. The operations staff are responsible for writing documentation with a higher level of specificity that can be used by observatory technicians. This division of labor is helpful since the operations team has the best knowledge of what is needed by the staff who will operate the instrument.

We consider the institutionalization of knowledge of the operation of the Keck Interferometer essential for the success of the instrument. While we consider documentation to be an essential ingredient of the Handover process, it is not a replacement for institutional knowledge. We define the institutionalization of knowledge as when operations staff can train other operations staff to successfully execute a task. The model we strive to follow is that the first time this process (operations staff training other operations staff) is undertaken, it is overseen by a development team member and not considered complete until the development team member concurs.

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We validate the Handover process components, training and documentation, by a phased operation approach. First, operations staff are incorporated into a particular task along with the development team. In the next phase, operations staff are responsible for a task with assigned development team support. In the final phase, the operations team is responsible for the independent completion of a task. In the context of regularly scheduled engineering observing, the set of tasks the operations team is independently responsible for is constantly enlarged. The final task is bringing the interferometer up from a cold start to operation on the sky.

The present state of the Handover is that CARA observatory staff are capable of operating all major interferometer subsystems. This was first demonstrated in November 2001, and is now the norm during observing runs. The majority of the tasks necessary to prepare the interferometer for the sky observing can also be done by CARA staff. The next major milestone for the Handover will be bringing the interferometer up from a “cold start” and successfully taking useful data on the sky. Before the Visibility Science mode Handover is considered complete, this milestone must be demonstrated.

2.3.2. Observing – Setup

- Access to data from previous observations
- Well-defined procedure for retrieving results from previous observations of a target
- Well-defined setup and alignment procedures and tools
- Summit staff performs routine tasks

2.3.3. Observing – Operations (with the Kecks)

- Demonstrate effective dual-telescope observing practices
- Devote some portion of each run to CARA-led operation
- Most operational issues cleared by CARA personnel
- Well-defined target acquisition, angle tracking, fringe tracking, data collection, and calibration procedure
- Siderostats fully functional and routinely available

2.3.4. Observing – operations (with Siderostats)

- Siderostats upgraded and returned to service as soon as possible
- Siderostats routinely available for observing

2.3.5. Maintenance

- Cryofills performed properly
- Cleanliness policy; adequate supplies, etc.
- Monitor spares availability
- Procedure for safely cleaning optics

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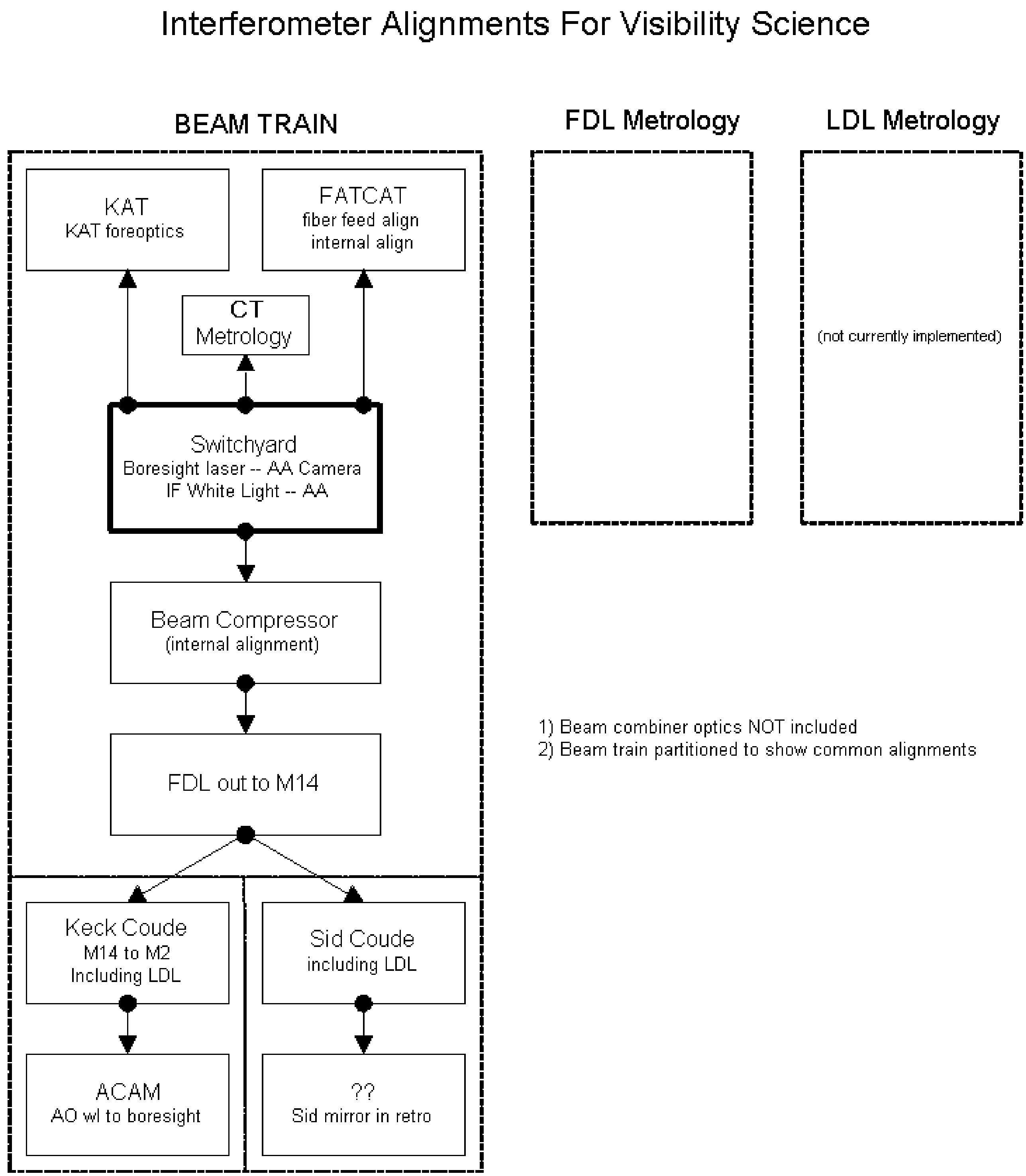

Figure 3: The inter-dependency of the alignments of different subsystem assemblies. The arrows show dependency flow.

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3. CONCLUSION

The general framework for the implementation of the Visibility Science Handover process has been put in place. We believe that our decomposition of the problem of transitioning a complex instrument, with extensive ongoing development, to a world class operational observatory, has been working well. The integration of operations staff into the development team at an early stage has greatly helped strengthen the details of the process. This model is one where many people directly involved in the Handover process contribute to the details of the process as it unfolds; it provides a framework to support these contributions. Our Handover process strongly contrasts with one where a few people try define the process details in advance. The latter approach is not realistically compatible with an aggressive development project of sufficiently large scope that no one individual can understand all the details.

Progress has been made on most fronts, however, equipment failure and a spate of bad weather during observing runs in the first half of 2002 has hampered its progress. Personnel have been assigned tasks in writing and reviewing handover documents at JPL and at CARA. Currently the process of reviewing, testing, and rewriting drafts of these documents and procedures is underway. The siderostats have been upgraded in hardware to parallel the metrology systems that are used for Keck-Keck observing. In their present state they are in their closest possible resemblance, hardware and software wise, to the Keck interferometer. CARA personnel have achieved internal fringes with them and expect to observe stellar fringes in the very near future. The Visibility Science Handover process will then be truly underway.

ACKNOWLEDGEMENTS

The Keck Interferometer is funded by the National Aeronautics and Space Administration as part of its Origins Program. The work described herein was conducted at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation.

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